#118

PRELIMINARY DATA
SUBJECT TO REVISION
10-6-89

NSWC TR 88-

UNDERWATER BLAST EFFECTS FROM EXPLOSIVE REMOVAL OF PLATFORM LEGS

CONTENTS

DRAFT

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Foreword

The underwater explosion measurements discussed in this report were conducted by the Explosion Dynamics Branch (R15) of the Energetic Materials Division (R10). The work was supported by the Conservation Division of the Minerals Management Service, U. S. Department of the Interior.

Facilities were provided by Offshore Petroleum, Inc (OPI) under contract to EXXON Corporation, with whom the responsibility for platform removal lay. Explosive charges were supplied, armed and fired by DEMEX International, under subcontract to OPI.

Underwater explosion data were collected and analyzed to determine the underwater shock output levels near underbottom well severance explosions. All shots were fired in the Gulf of Mexico at the former location of E_{XX}ON's West Delta 30 platform. Data was recorded and analyzed with the R15 digital data acquisition system.

Company and trade names are mentioned in this report for information and identification purposes only. Endorsement or criticism is not intended.

The R15 field crew included: R. E. Mersiowsky, D. R. Kulp, S. E. Coghill, K. W. Rye and J. G. Connor, Jr. Gages were constructed, calibrated and repaired as needed by S. E. Coghill at Dahlgren. Preliminary set-up and rig construction was done at Dahlgren by R. E. Mersiowsky, B. A. Robey and B. E. Sebring.

Digitization of analog tape records and final computer analyses were run at the White Oak site by J. C. Floyd.

Approved by

K. F. Mueller, Head
Energetic Materials Division

Chapter 1

INTRODUCTION

BACKGROUND

Oil well platforms located in 50 to 500 ft of water are often set astride navigable waterways. Those platforms that have served their purpose are eventually cleared to at least 15 ft below the mud line. This is done to avoid profligate growth in numbers of navigation obstacles and snags for fishermen's nets.

Platform removal is most efficiently accomplished by detonating an explosive charge inside each of the various hollow members that penetrate the sea bottom. Following the severance explosion(s), submerged portions of the structures are pulled from the water and placed on barges for removal. It is required that the explosive severance operation be carried out with minimum effect on marine life.

Two aspects of the explosive output from well severance operations remain largely unquantified: the threshold levels at which marine life is irreparably damaged, and the actual levels found near a typical severance operation.

Direct study of the first of these - survivability of marine life forms under explosive shock stress - has been proscribed by fiat. Our goal in the present project has been to examine the other aspect of the problem: determination of the shock levels output during a typical explosive removal operation. In this report, discussion is limited to evaluation of shock output levels at various positions; consideration of the consequences to marine life forms is left for others.

The original plan was to conduct controlled half scale tests in the Potomac River. The properties and construction of the hollow members driven into the mud bottom would be well known and documented, and the locations of the gages used to examine the shock fronts would be known to within a few inches. There was also a plan to tether biological specimens near explosion sites at known standoffs; the specimens were to be examined after each shot to determine the extent of their injuries, if any. Ecological considerations prevent this or any other firing in the Chesapeake Bay and its tributaries including the Potomac River.

A "typical" well platform scheduled for removal was found which could be instrumented without undue interference with the removal operation. All parties involved were not unwilling to allow diagnostic shock pressure measurements.

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WEST DELTA 30 PLATFORM

This platform was installed in 1964. Its field had been exhausted by the mid eighties and it was scheduled for removal by a subcontractor to the EXXON Corporation in the Fall of 1988. It was located about 10 miles offshore in the Gulf of Mexico south of Grand Isle, LA.

Dimensions of the platform are shown in Figure ____. It was located in 53 ft of water. The bottom penetrations included the main piles for two six leg jackets, eight skirt piles, six dolphin piles and nine well conductors. As many as 14 conductors were used during the active lifetime of the platform; only 9 remained at the time of the removal operation.

DERRICK BARGE OPERATIONS

A flotilla was supplied by Offshore Petroleum Industries (OPI) for the removal of West Delta 30. It consisted of several tug boats, a supply boat and the DB II barge. The DB II was the primary staging platform from which welders, divers and riggers worked to remove the well platform from the Gulf. It is a derrick barge approximately 350 ft long by 125 ft wide. The barge was held immobile by six anchors on 1000+ ft cables. Position was adjusted by operating the steam winch on each cable. It carries a crane capable of lifting the severed 6 leg jacket from the water when the diver, riggers and ordnance crews completed their tasks. It also provides sleeping and eating facilities for off-duty personnel; each of two crews worked a 12 hour shift daily so that the operation continued 24 hours a day.

The first step in the operation was the excision of the superstructure - everything above the jackets. Completion of this effort left the jacket legs extending about 10 ft above the water. The skirt pile tops were 10 to 15 ft below the water line, and the dolphin pile tops were about 10 ft above the water. The well conductors extended various distances from a few feet below to 20 ft or so above the water.

Next, mud and silt were "jetted" out from the inside of each bottom penetrating member. Each charge was armed and lowered to the prescribed depth in the structural member or members being severed.

For each shot, when the charge(s) had been placed and armed, the anchor winches were used to pull the barge away from the platform as the NSWC crew paid out the gage string and cables. Barge motion was finely enough controlled that the long axis of the vessel remained parallel to its original position beside the platform. That is, the steam winches were capable of maintaining the barge axis parallel to its original direction as it was moved away from the platform.

The placement of the instrumentation van used by NSWC for the underwater pressure measurements is shown in Figure ___. The barge is shown in the figure standing off from the well platform in the position for firing. Upon completion of firing, the anchor winches were used to move it back next to the platform. There, the riggers, divers and ordnance personnel prepared for the next shot by removing the severed portions of the structure, jetting mud from the next members to be severed and setting new charges.

CHARGES

All the charges were Composition B and were prepared, armed and fired by DEMEX International - a subcontractor engaged by OPI.

The well conductors were shot with 25 lb cylindrical charges. One conductor was cut with a 50 lb toroidal charge. The jacket legs and various piles were all shot with 38 lb octagonal charges - shown in Figure ___.

Charge Confinement

The design plans including the structural details of each of the bottom-penetrating members are not available. As will be seen below, however, the explosive output differed little between the various legs. Thus, the passage of years - with attendant corrosion - functioned to "level the playing field". The bottom penetrating members were roughly equivalent to one another in their shock attenuating capabilities.

Skirt Piles. These consisted of a single thickness of pipe with their tops well below the water surface.

Jacket Legs. These consisted of a structure constructed on shore, carried by barge to the site and set in place on the bottom. Each jacket was held in position by main piles driven through each of its legs to bedrock. There was therefore a single thickness of pipe betwen the explosive and the surrounding mud.

Well Conductors. These are of somewhat smaller diameter than the jacket legs and are constructed of at least two layers of pipe with cement grout between layers. Two of the six were "underwater stubs": their tops were underwater rather than in the air above the water surface.

PRESSURE GAGE STRING

Figure ___ shows a typical configuration of the gage string. The outboard end is tied to a convenient point on the platform so that the submerged lines are not likely to become entangled in whatever debris or portions of the platform are below the water surface. This required that, for some shots, the close-in gage line be considerably more than the planned 10 horizontal feet from the location of the buried charge. In addition, due to subsurface currents, the gage string could not be pulled straight without the possibility of overstraining, if not breaking, the cables.

Locations of the gages were estimated. The estimate begins with determining the horizontal standoff of the float above the first vertical gage line from the nearest point on the platform. This gage was then located relative to the exact leg/conductor/pile being shot from dimensions on the available drawings of the platform. An estimate of the curvature of the line of floats caused by the currents then provided estimates of the horizontal locations of each of the other vertical gage lines. This procedure assumed that the vertical gage lines were, in fact, vertical. Twelve pound weights were attached to the lower end of each gage vertical to counter their tendency to rise in the current. There was no way to check this assumption. Also, there was no accurate way to determine the actual standoff of the first gage float from a particular portion of the platform. All-in-all, the gage locations are <u>not</u> well known.

It is not possible to use the NSWC ranging program to determine the gage locations. This program was designed to be used for bare cylinder charges fired in free water with a fiducial signal that is generated by the shock as it passes the surface of the charge. Buried chgs enclosed in steel - -

- S/w passes through bottom mat'l & water
- fiducials not on surface of chgs

INSTRUMENTATION

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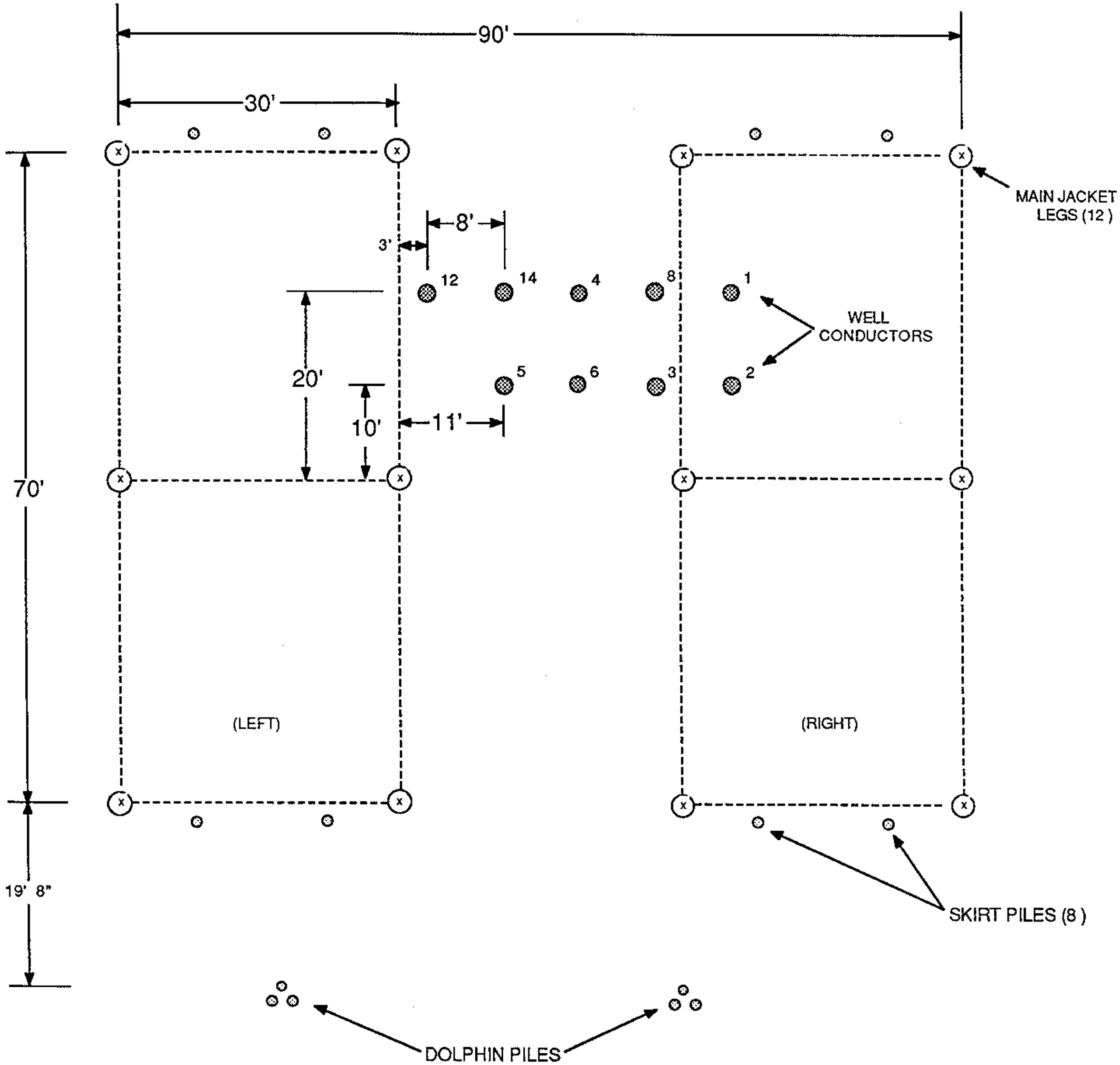
Gages

Tourmaline gages were mounted on steel fingers attached to vertical "down lines". On each line there was a single gage at 20, 35 and 49 ft below the water surface. Since the mud line was approximately 53 ft below the water surface, the lowest gage on each string was 4 ft off the bottom. The first down line was intended to be 10 ft (horizontally) from the charge location for each shot; in no case was it possible to place the line this close. The second line was 15 ft beyond the first; the third was 75 ft beyond the second and the fourth was 200 ft beyond the third. The total horizontal arc length of the gage line from the first to the fourth down line was therefore 290 ft.

Gage signal cables were run to the surface along each down line and supported by surface floats back to the barge.

Electronics

The signals from the tourmaline pressure gages were fed to impedance matching and termination networks via about 400 ft of special low noise coaxial cables. Signal conditioning circuitry placed the signals on a 14 channel Racal analog FM tape recorders. The tapes were run at 120 IPS and the recorder frequency response was 500 khz. Playback frequency responses of 500, 250 and 125 khz were accessible by selection of playback electronics; 125 khz was selected. Immediately following each shot, the analog tape records were played back on visicorders to assist identification of faulty gages and to allow timely judgments of gage condition and of the quality of the data as it was obtained.



WEST DELTA 30 PLATFORM GEOMETRY

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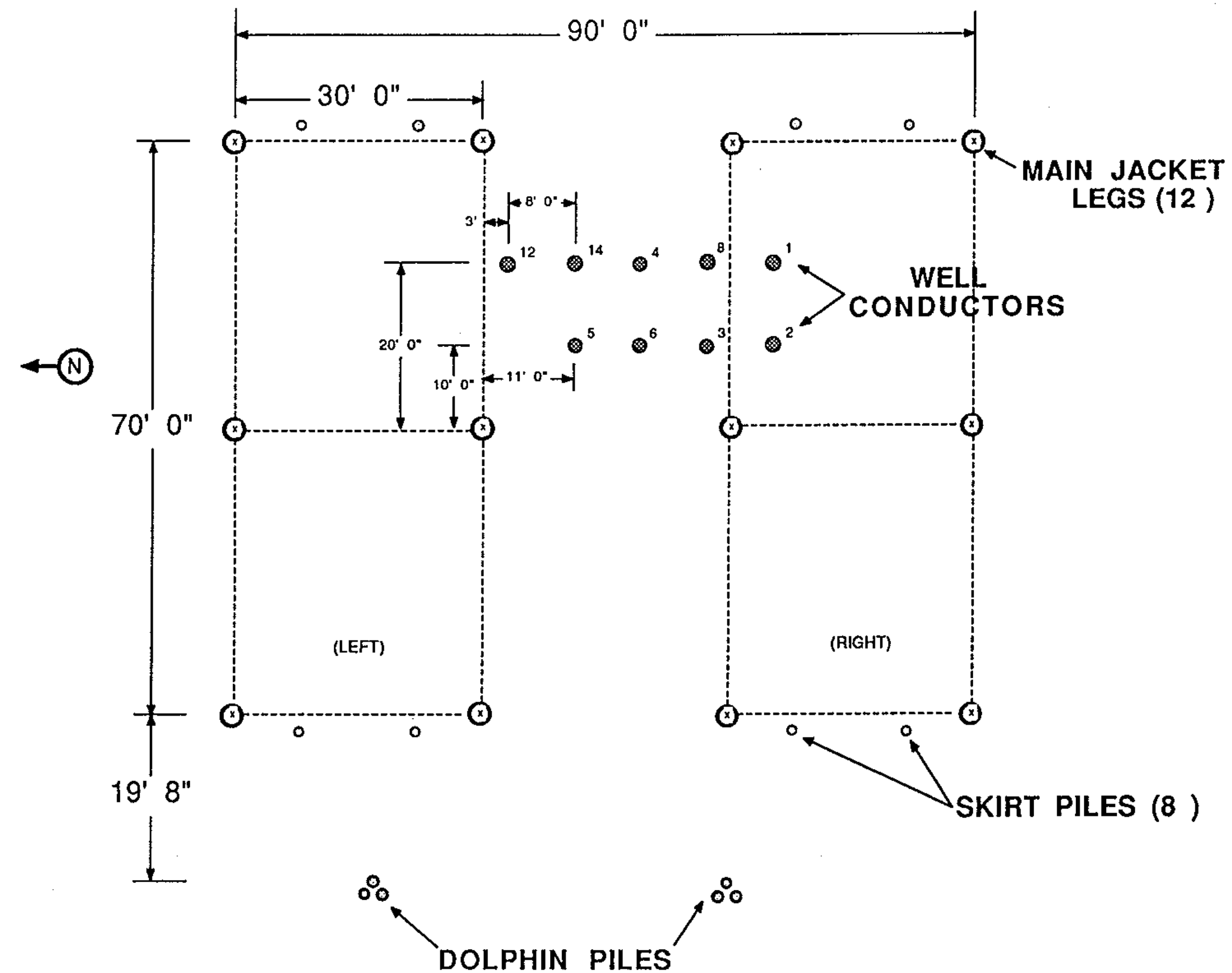

WEST DELTA 30 PLATFORM GEOMETRY

(PLAN VIEW)

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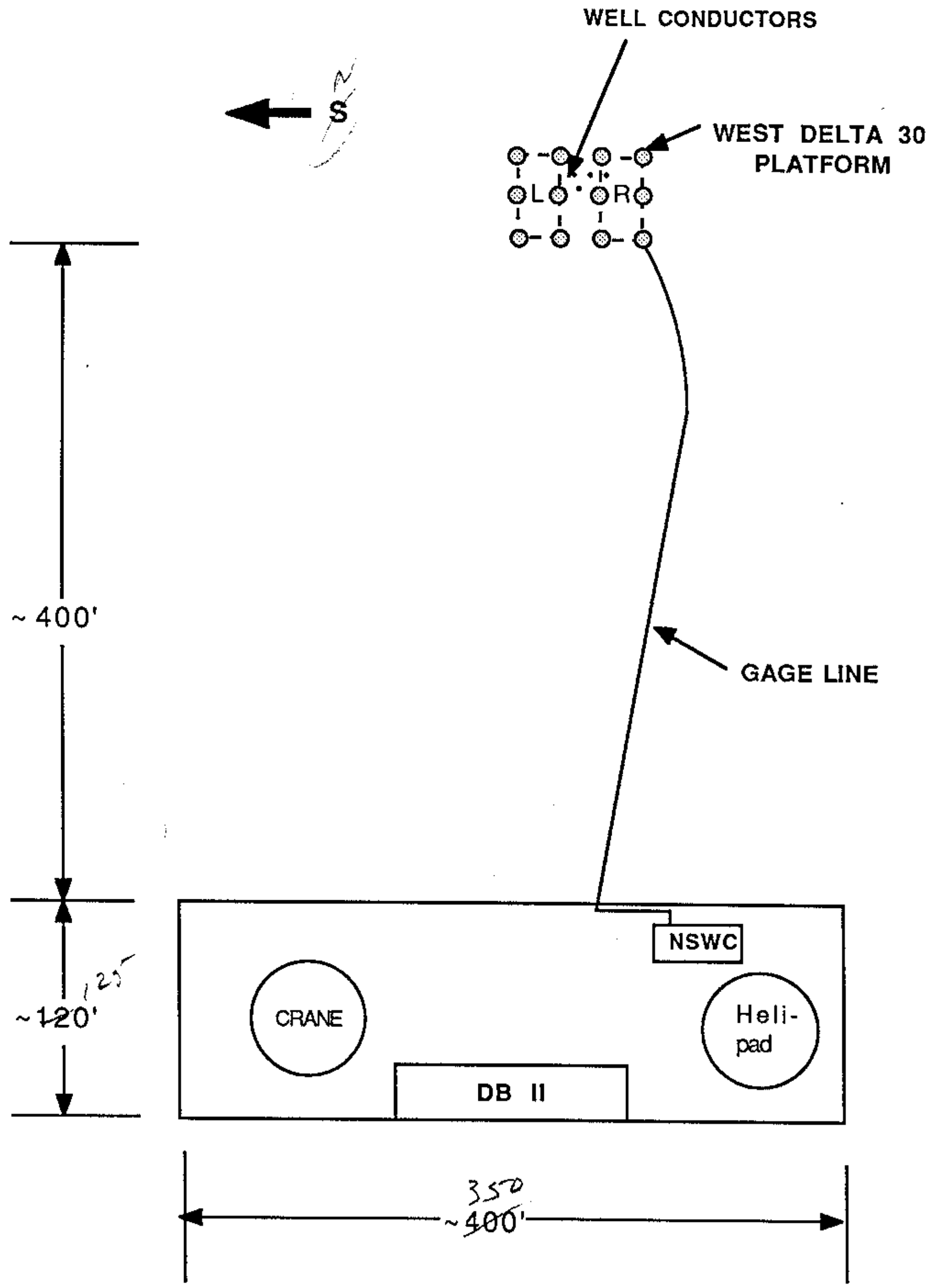
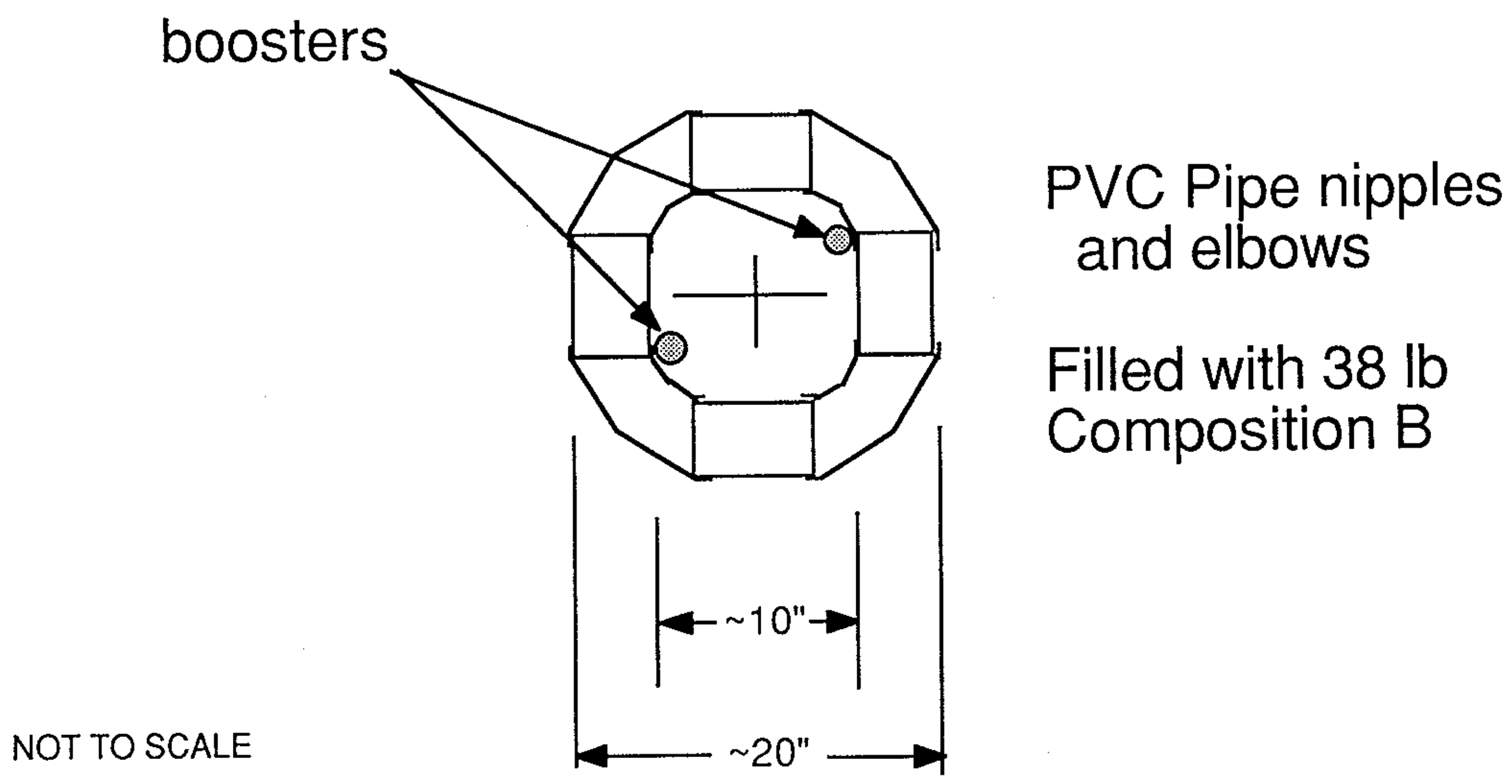
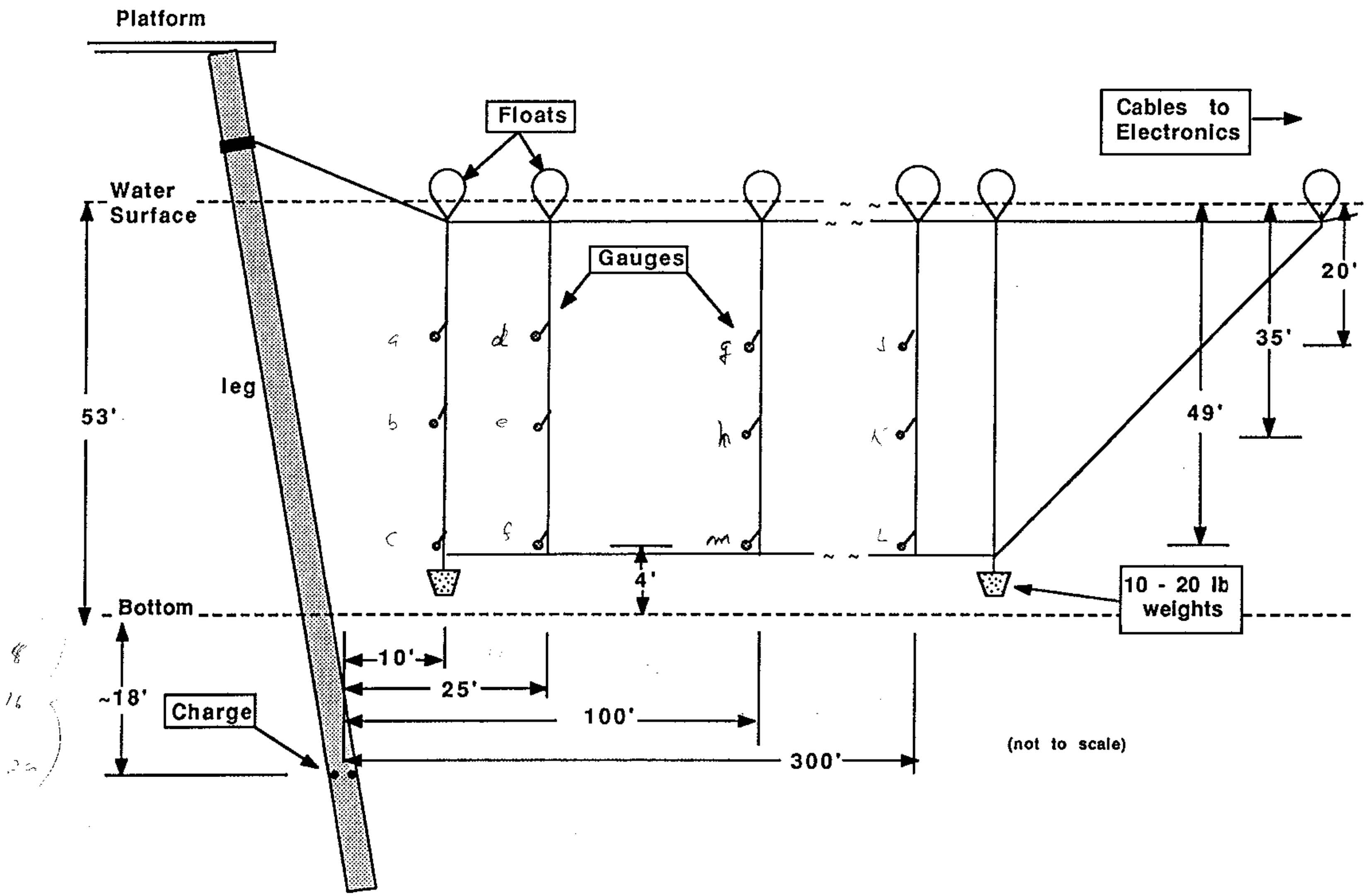


(not to scale)

FIGURE SCHEMATIC OF GAGE LINE, BARGE & PLATFORM



OCTAGONAL CHARGES



GAUGE RIGGING

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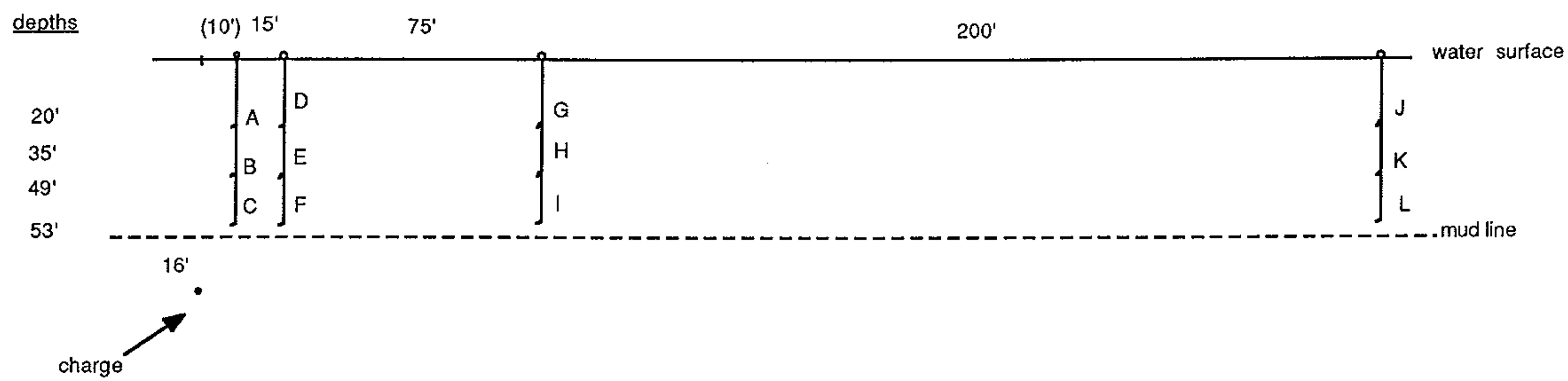
5.

Gage Rig Dimensions



Chapter 2

PREVIOUS WORK

Few qualitative studies of the explosion shock output from underbottom detonations have been reported. Two which appear applicable to the present problem are discussed briefly in this section. Unfortunately, neither is readily accessible in the open literature.

The first study was a series of large free water Comp C-4 explosions. They were fired to accumulate shock data from which generalized similitude equations were generated.

The second study might be considered the genesis of the present project. Simulated wellheads were severed under rather more controlled conditions than were possible on the West Delta 30 removal operation.

FREE WATER TESTS

Three 65 lb Comp C-4 charges were fired in free water in the Potomac River as part of a broader series of tests. Results were reported in an internal memorandum.

Shot Geometry

Charges and gages were placed on a float supported string rig such as is commonly used for free water tests. Charges and gages all were placed at a depth of 30 ft in 70 ft of water. Gage ranges from each charge were 5, 8, 15 and 65 ft; these ranges correspond to scaled ranges of 1.24, 1.99, 3.73 and 16.17 ft / $lb^{1/3}$.

Results

Shock similitude equations were determined for these charges. The similitude equations express peak shock overpressure, specific shock impulse and shock energy flux density as a function of reduced range. (reference ____.)

Reduced range is defined as actual range in ft divided by the cube root of charge weight in lbs. Peak overpressure is the maximum initial excursion from ambient of the pressure gage signal when the shock wave arrives. Impulse is the integral under the pressure-time signal produced by the shock; the integral extends for 1 time constant of the initial decay for these charges. Energy flux is proportional to the integral of the square of the pressure amplitude, again for a duration of one time constant.

The similitude equations determined for the 65 lb charges are:

Overpressure: $P = 27150\ (R/W^{1/3})^{-1.22}$ (psi)

Impulse: $I = 1.45\ W^{1/3}\ (R/W^{1/3})^{-.919}$ (psi-sec)

Energy: $E = 2950\ W^{1/3}\ (R/W^{1/3})^{-2.13}$ (in-lb/sq-in)

In these equations,

R = Range (ft) and W = Charge Weight (lb)

These results are presented graphically with the results of the well head severance tests discussed in the next section.

HALF SCALE WELLHEADS

Several explosive tests using half scale models of oil wellheads were conducted by NSWC (Reference ___). These tests were perfomed in the Potomac River at Dahlgren, VA to determine the characteristics of the pressure field in the water near explosions confined in simulated well conductor casings. The casings were severed both in free water and with the charges 7.5 ft below the mud line.

Three explosives were used: Comp C-4, TNT and Nitromethane. Of the three, Comp C-4 provided the greatest output levels: results are discussed in the following. (reference ____)

Shot Geometry

Twenty two tourmaline gages were mounted on three vertical down lines spaced 4, 9 and 14 ft from the down line on which the charge and simulated well casing were mounted. For the underbottom shots, six of the gages were on the bottom, three were just under the water/air boundary, five were near the bottom and the remaining eight gages were located at middle depths in 25 ft of water. The closest gage was ___ ft (___ ft/lb$^{1/3}$) from the charge; the farthest gage was ___ ft (___ ft/lb$^{1/3}$) from the charge

The simulated casings were hollow, and were vented to the air above the charge.

Results

Shock wave peak overpressure, specific shock impulse and shock energy flux density were determined for each gage. The results are presented in graphical form: overpressure in Figure ____, impulse in Figure ____ and energy in Figure ____. The upper line on each figure shows free field values determined from the 65 lb shots described above. The lower line represents a least square fit to the values obtained with the charge beneath the mud line in simulated well casings. No allowance was made for the mud fraction of the path between each charge and gage. The only distinction made in the data presented is that the pressure values obtained from gages within 30° of the vertical line above the charge cluster about a different, lower, line than those from gages located further from the vertical. Despite this, impulse and energy values from the gages at angles greater or less than 30° are not clearly distinguishable from one another.

Pressure and impulse values for the mud shots, represented by the lower fitted lines in each case, were reduced to about 36% of the values observed at the same reduced ranges in free water. Energy values were reduced to about 15% of the free water values. These percentages are a rough measure of the attenuation provided by the mud and pipe confinement. They are the ratios of the values of each parameter at approximately the midrange of the measurements: 10 ft/lb$^{1/3}$.

The energy attenuation is considerably greater than that for either the impulse or overpressure. This is consistent with the fact that the energy is proportional to the square of the pressure. When the pressure is reduced by a factor of 0.36 the energy is reduced by a factor Of $0.36^2 = 0.13$. The impulse is reduced by the same factor as is the pressure.

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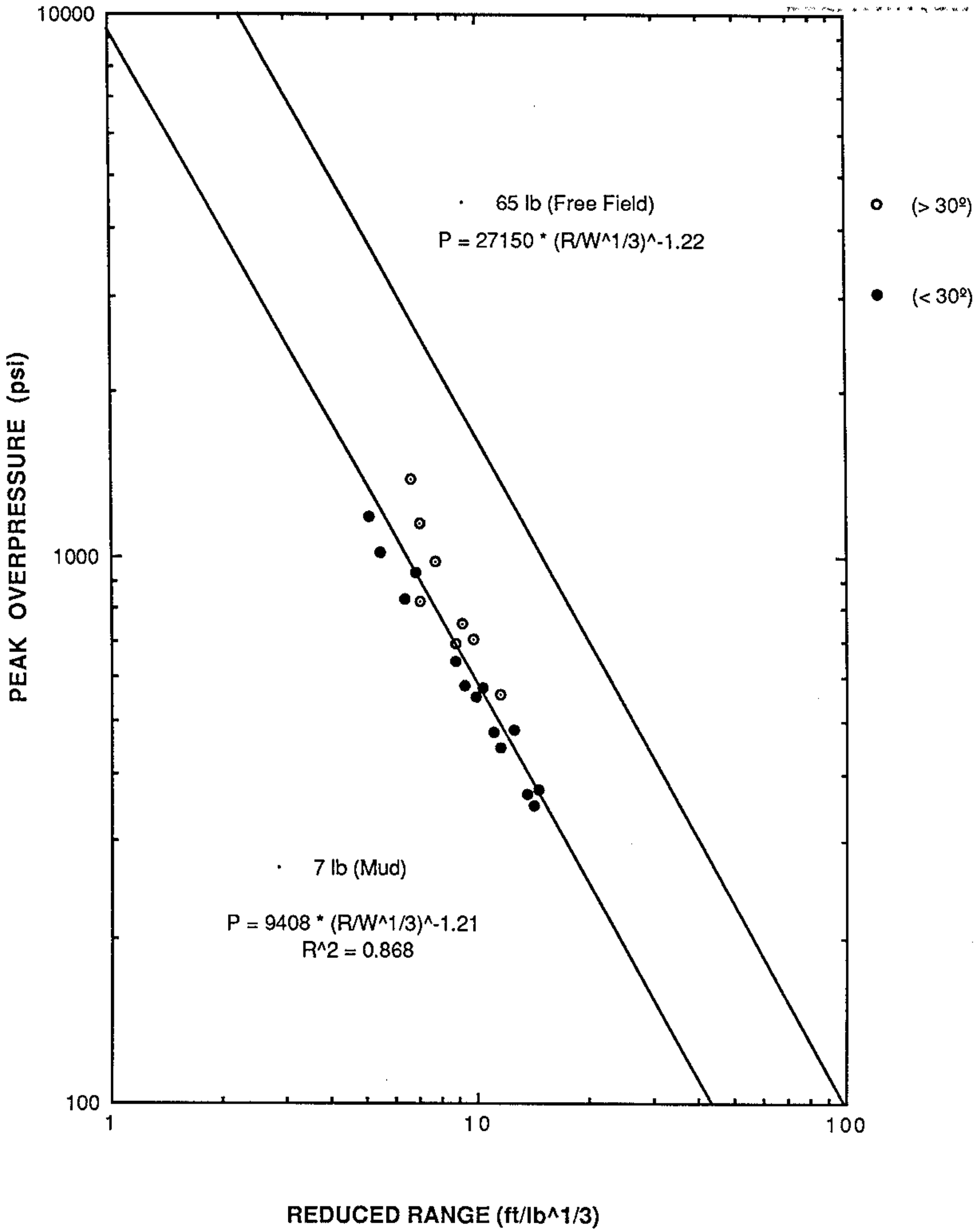
References:

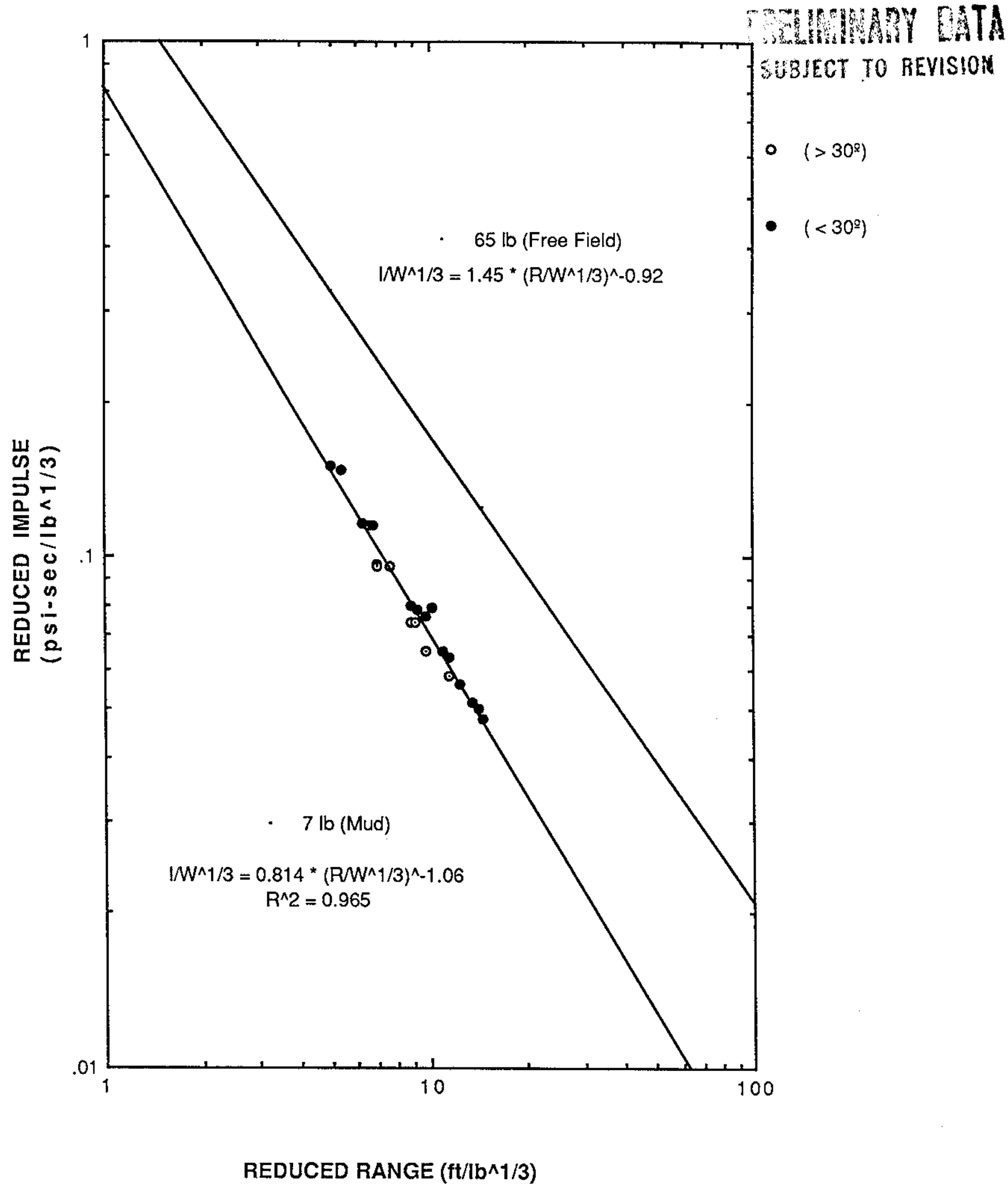
Cole, R. H., Underwater Explosions, Princeton University Press, 1948

Faux, W. H., "A Cursory Look at the Environmental Effect of the Severing of Oil Wellheads," Transactions of the 1981 Explosives Conference June 9-11, 1981, Houston, TX, Sponsored by the Drilling Technology Committee of the International Association of Drilling Contractors.

Goertner, J. F., "Fish-Kill Ranges for Oil Well Severance Explosions," NSWC-TR 81-149, April 1981



HALF SCALE OIL WELL REMOVAL TESTS



HALF SCALE OIL WELL REMOVAL TESTS

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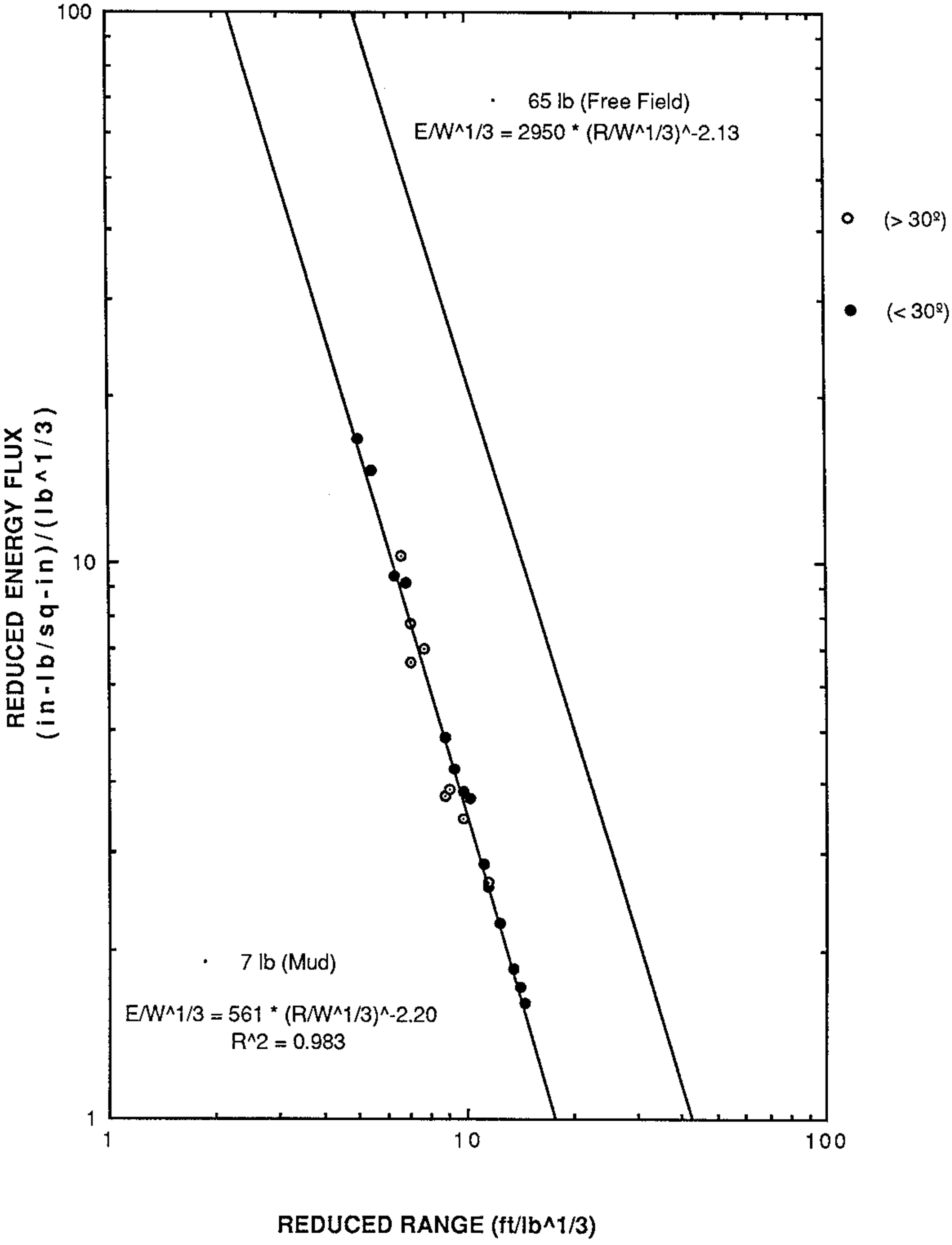

HALF SCALE OIL WELL REMOVAL TESTS

Chapter 3

ANALYSIS

SHOTS FIRED

In the course of the removal operation, eleven groups of platform elements were severed beneath the mud line. Some "groups" involved only one element; others involved either two or six fired at one second intervals. All the bottom penetrating elements that were shot and whose shock waves were recorded are listed in Table ____.

GAGE POSITIONS

The major reason for NSWC participation in the operation was to collect data from which to generate similitude-type equations. These equations are used to predict the output from other similar explosions. To determine these equations with any degree of precision, the location of each gage relative to the explosion site must be known.

The calculation normally used to determine slant range for a gage near a free water explosion is based on the shock transit time in water between the charge surface and each gage. However, the charges in the present tests were not located in free water, and it was not feasible to mount a fiducial gage on each charge. Therefore, the normal ranging algorithm could not be used. The geometric calculation that was used is described in the following.

Horizontal Ranges

The gage line was tied to a ~~reachable~~ CONVENIENT point on the platform structure on the side closest to the barge. The tie point was chosen to minimize the possibility of snagging underwater portions of the string on submerged debris or structural elements. As the barge backed off from the platform, the ambient current pulled the line sideways. The shape of the curved surface line was reproduced on a scaled drawing of the barge/platform arrangement. A generalized sketch is shown in Figure ____. The Cartesian coordinates relative to the tie pint of each of the floats supporting a gage down line were read from the drawing.

The horizontal coordinates of the charge relative to the tie point were determined from a freehand drawing of the system. These coordinates were used with the horizontal coordinates of each down line to determine the horizontal range from the charge to each down line. The geometry is illustrated in Figure ____a.

Slant Ranges

The horizontal range, the charge depth below the mud line and the height of each gage above the mud line were used to determine the slant range from the charge to the gage. The geometry and Pythagorean calculation are illustrated in Figure ___b.

Precision

The procedure described above involves a number of assumptions that cannot be avoided, given the nature of the operation:

Charge depths below the mud are uncertain (+/- 18"?)

Curvature of surface float line was estimated

The gages are assumed to hang vertically directly below the floats

Position and length of tie line to 1st gage uncertain +/- 2' or 3'

As a result of these ambiguities, the magnitude of the uncertainty in the slant range of each gage is estimated to be at least 5 ft.

DATA REDUCTION

Analog magnetic tapes were analyzed with the KIS Explosion Effects Program and associated hardware.

Digitize

Rate:

Reduce

Convert digitized voltages to pressure
Integrate to find impulse and energy for 1st & subsequent shocks

Interpret
? ? ?

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TABLE 1

SHOT LOG

NSWC Shot No.	Date (1988)	Time	Charge Weight (lb)	Depth Below Mud (ft)	Top of Tube*	Target
----	12/11	1000-1300	40 ea.	16	+5'	5 Dolphin Piles
----	12/12	0850	40	"	"	Dolphin Pile
		"	25 ea.	"	+10'	Well Conductor # 2 & 6
2873	12/12	1131	25	18	-45'	Well Conductor # 8
2874	"	1239	25	18	-45'	Well Conductor #14
2875-1	12/13	0900	50	20	>+10'	Well Conductor # 1
2875-2	"	"	25	20	"	Well Conductor #12
2876-1	"	1010	25	20	"	Well Conductor # 3
2876-2	"	"	25	20	"	Well Conductor # 5
2877	"	1123	50	20	"	Well Conductor # 1
2878-1	12/14	1403	38	16	+10'	North Main Pile
2878-2	"	"	"	"	"	" " "
2878-3	"	"	"	26	"	" " "
2878-4	"	"	"	16	"	" " "
2878-5	"	"	"	"	"	" " "
2878-6	"	"	"	8	"	" " "
2879	12/15	0725	38 ea.	26	-20'	2 North Skirt Piles
2880	"	0727	" "	16	+10'	6 South Main Piles
2881-1	"	0848	"	26	-20'	North Skirt Pile
2881-2	"	"	"	16	"	North Skirt Pile
2882	"	1015	" ea.	"	"	2 South Skirt Piles
2883	"	1128	" "	"	"	2 South Skirt Piles
----	12/16	0900	external shaped chg		+30'	Well Conductor # 4

* Approximate vertical separation from water surface:
> 0 : above water
< 0 : submerged, below water

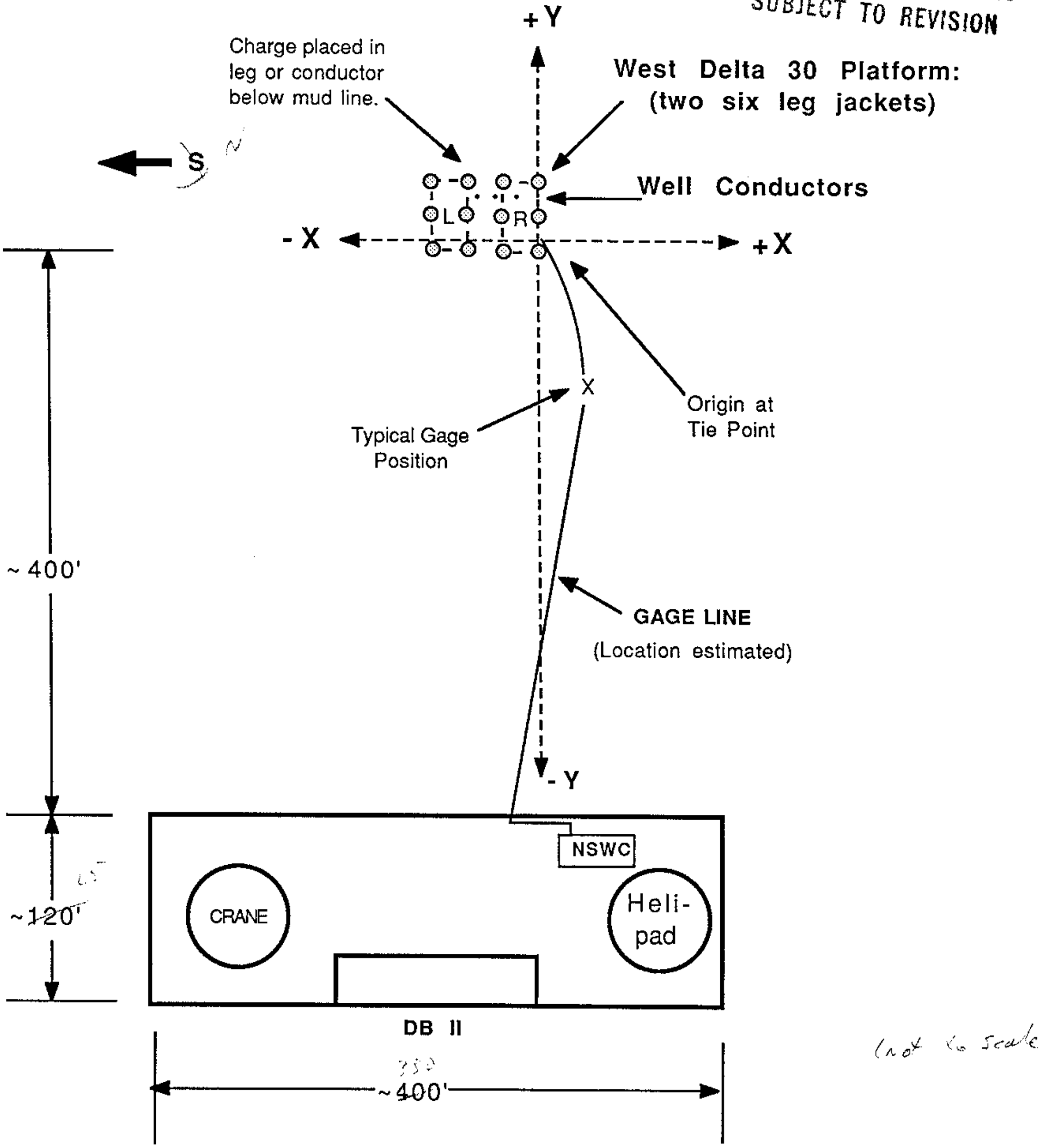

FIGURE : GAGE LINE, BARGE & PLATFORM GEOMETRY

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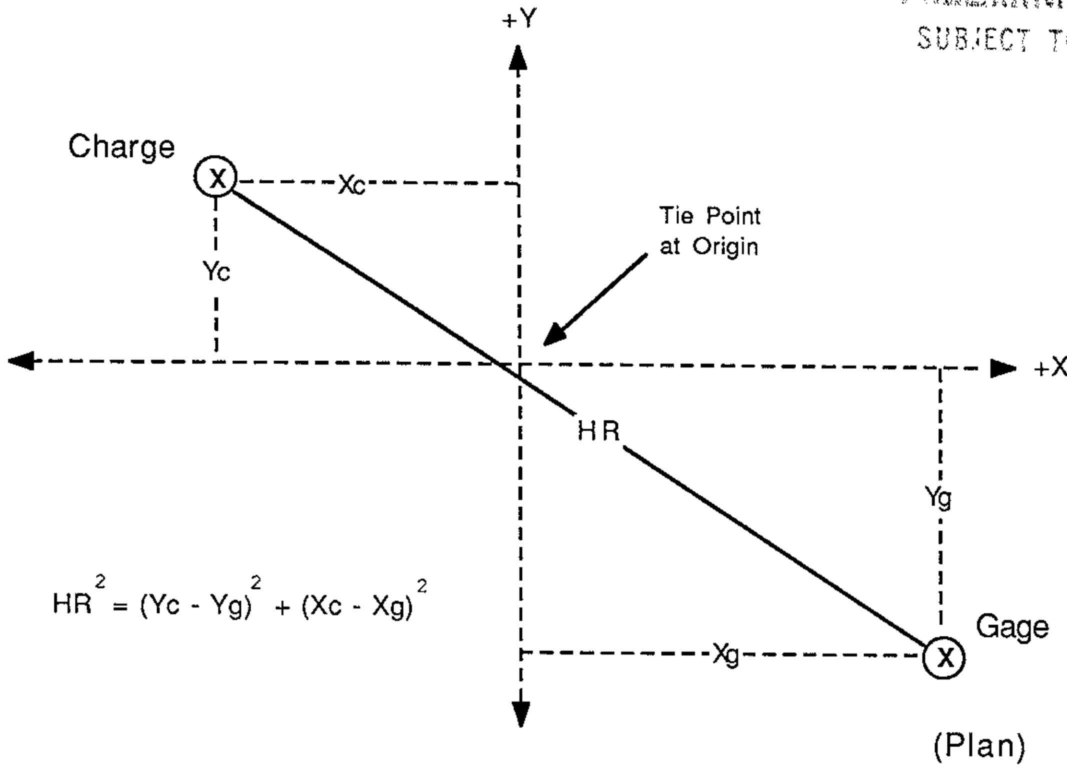
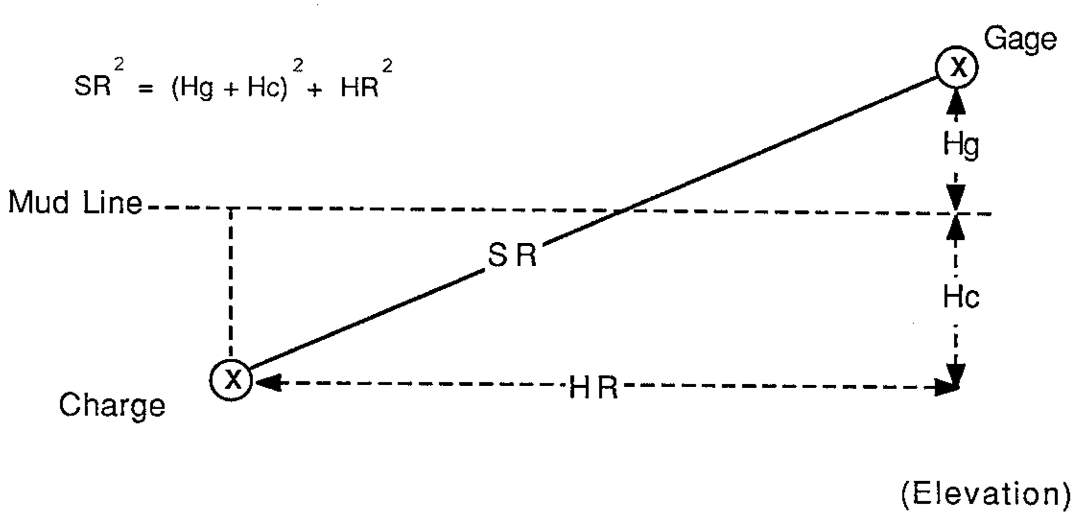


a. Horizontal Range Calculation



b. Slant Range Calculation

FIGURE GAGE RANGE CALCULATIONS

Chapter 4

RESULTS

VARIABLES

Three parameters that varied among the test explosions were: location of the open top of the tubular, the size of the explosive charge and the depth of the charge below the mud line. These could not be varied in a systematic and controlled manner, but their effects are noted as far as possible.

Top of Pipe

The tops of most of the severed tubulars extended above the surface of the water. The exceptions were the skirt piles and two of the well conductors: their tops terminated 10 ft or more below the surface of the water. The tops that were below the surface of the water were not cut expressly for this operation; cutting done in connection with the removal operation was terminated above the water surface primarily for cost effectiveness reasons and job efficiency.

Charge Size

The bulk of the data analyzed here were obtained with Composition B charges weighing approximately 38 lb. They were roughly toroidal in shape, detonated at two points - at either end of an inner diameter. The 25 lb charges were 2:1 cylinders, fired inside well casings. The 50 lb charges were donuts. The cylindrical charges were detonated at their upper ends. The charge sizes were chosen to ensure severance of the tubular and not to give a range of weights for the present analysis.

Charge Depth

The mandated severance depth for platform clearance is 5 meters (~16 ft) below the mud line. The 25 and 50 lb charges used in the well conductors were placed either 18 or 20 ft below the mud line. Of the 38 lb octagonal charges used in the piles and platform legs, one was placed 8 ft, and one 26 ft below the mud line. The remaining 18 charges were placed 16 ft below the mud. These depth variations were made to assess the effects of depth of burial on shock output of the explosions. (A waiver was granted for the shallow severance shot.)

PRESSURE PULSE CHARACTERISTICS

In this section the features of the underwater shock pulses emitted by the underbottom severance charge explosions are described. For the multiple shots - those on which two or more charges were shot at 1 sec intervals - no interference between pulses was observed.

Air Termination

For those cases in which the charge was fired in a tubular whose top end terminated above the water surface, a single major pulse was observed. The major pulse was preceded by a smaller pulse, and the pair was followed by a long duration low amplitude negative excursion.

Jacket Legs. All were 38 lb octagonal charges.

Conductors. three 25 lb cylinders, one 50 lb donut

Water Termination

For those cases in which the charge was fired in a tubular whose top end terminated below the water surface, three shock pulses were observed. On first viewing, the sequence of pulse arrival times seems strange. The first two of the three arrive at the top gages on each down line earlier than at the lower gages on the same line. The third pulse arrives at the lowest gage on each line before the upper gages on the same line.

Since the charges all were mounted below the lowest gage, the direct shock emitted by the explosion should arrive, first, at the lowest gages on each string (because of the shorter travel distance), reaching each higher gage in upward succession. Conversely, a shock originating near the water surface should arrive, first, at the topmost gage in each string, then arriving at each lower gage in downward succession.

Following the above argument, the first pulse appears to originate at the top of the tubular: a shock is emitted from the open end into the water, and is the first to arrive at each of the gages on a guven down line. This first pulse exhibits a shape typical of surface cut-off. A shock is emitted from the submerged top of the tubular and is reflected at the water surface as a rarefaction. The reflected rarefaction arrives at each gage before the direct shock pulse has decayed to ambient. This causes the pressure signature amplitude to drop sharply to ambient. (reference ____ (Cole))

The second pulse at each station arrives at a time consistent with having originated nearer the water surface than the bottom. Its apparent source is not obvious. It exhibits some of the characteristics of the smaller pulse that precedes the direct shock wave observed on the air-terminated shots. It has about the same amplitude at all depths and it arrives earlier at the shallower gages (nearest the water surface).

The third pulse to arrive at each gage station is apparently the direct shock emitted from the charge inside the tubular below the mud line. Its time-of-arrival (TOA) is later for the shallower gages. The pulse does not exhibit the characteristic surface cut-off pulse shape.

Conductors. 25 lb cylinders

Skirt Piles. 38 lb octagonal charges

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COMPARISON

Half scale shots - (current) full scale "real life" shots

agreement ==> some sort of consistency.

118 B

NAVSWC MP 91-220

CONCISE METHODS FOR PREDICTING THE EFFECTS OF UNDERWATER EXPLOSIONS ON MARINE LIFE

BY GEORGE A. YOUNG

RESEARCH AND TECHNOLOGY DEPARTMENT

1 JULY 1991

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FOREWORD

The U.S. Navy has conducted a comprehensive program of research on the environmental effects of underwater explosion testing since 1970. This work has been documented in a series of technical reports and lectures. However, there is a need for brief, less technical, publications that can be distributed to regulatory agencies and the general public to clarify certain issues prior to the conduct of tests. As the physical effects of explosions on marine life usually receive more scrutiny and discussion than any other potential environmental effect, this topic has been given priority and is the subject of this report. It is expected that other topics will be treated in subsequent publications.

This report was prepared as part of the Ordnance Reclamation Project of the Naval Sea Systems Command (SEA 06R) under Program Element 63721N, Work Unit—Environmental Effects of Explosive Testing. This report is one of a series published under this sponsorship.

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TABLES

RESEARCH ON THE ENVIRONMENTAL EFFECTS OF UNDERWATER EXPLOSIONS BY THE U.S. NAVY

Experiments on the effects of explosions on marine life have been conducted since the 1940s by various organizations, but no satisfactory theory was developed to explain the results until the Navy initiated a systematic research program in 1970. The program has the following objectives:

- to conduct experiments on the effects of explosions on fish,
- to collect useful data from all possible sources,
- to develop prediction models based on sound theoretical concepts for injury to marine life,
- to investigate the deposit of explosion products in the atmosphere and marine environment,
- to develop prediction models for concentration levels based on explosion and dispersion theory,
- to develop methods to avoid or minimize all adverse environmental impacts,
- to investigate safe methods to cause marine life to temporarily leave a test site, and
- to provide technical support for compliance with relevant environmental laws.

This report is limited to the effects of explosions on common forms of marine life and on human swimmers.

Research was conducted in collaboration with fishery biologists at the Chesapeake Biological Laboratory in Solomons, Maryland. This partnership has been maintained to the present, and the body of accumulated knowledge has been a basis for consultation and involvement with almost all forms of underwater explosive work, including blasting, demolition, and channel clearance. Project personnel participated in tests against young salmon conducted in Alaska by the Oil and Gas Industry and worked with Minerals Management Service and National Marine Fisheries Service personnel on problems related to the explosive removal of offshore drilling platforms in the Gulf of Mexico. They also provided technical input at the Southwest Fisheries Center Seal-Bomb Workshop held in La Jolla in 1989.

During the early stages of research, emphasis was placed on studies of the effects of explosions on fish because of their dominant presence in the marine environment and their considerable economic importance. During later stages, special attention was given to marine mammals and sea turtles, which are present at some test locations. These species require maximum protection. Effects on swimmers were studied in other programs related to the safety of Navy divers, and the results are used here.

Since there is always a paucity of data for extreme conditions, such as very low dosages, low level physical effects, or natural events that rarely occur, predictions for low levels of probability are made by extrapolating data in the mid-range of probability.

When predications of the environmental effects of underwater explosion tests are made, statistical methods are used for calculating the probability of injury of common species of fish with and without swimbladders. A different approach is followed for endangered species, sea mammals, sea turtles, and human swimmers. As no injury is acceptable in these cases, the calculated safe range is based on data from land mammals that indicate levels of effects that are not injurious.

In the complete absence of data, relevant information and physical and biological concepts are used and a "worst case" analysis may be employed.

For convenience, the various forms of life encountered in coastal waters (generally within 12 nautical miles of land) have been divided into four categories of vulnerability, starting with those that are the least vulnerable. These are listed in Table 1.

Figures 1 through 7 include typical calculated ranges for the four categories of vulnerability in addition to sample contours for swimbladder fish, porpoises, and swimmers. When contours are available, the extreme range is used for planning. The equations used for range predictions are summarized in Table 2. In most cases, the original predictions were made with computer programs based on complex physical-biological models. The equations presented here summarize the results in a concise form for use in the initial stages of planning.

DEFINITIONS USED FOR TEST PLANNING AT SEA

MINIMUM AIRCRAFT SURVEY RANGE

This is the range at which spotter aircraft fly for a period of at least one hour prior to a test. If swimmers, sea mammals, or sea turtles are observed within this region, or approaching it, tests will be delayed until they have left. The range is based on safety of human swimmers, as this exceeds the safe distance for marine life.

MINIMUM SURFACE SURVEY ZONE

This is the close-in region that can be surveyed by personnel on shipboard, both visually and with fish-finders. It is usually based on the 90 percent survival of swimbladder fish weighing one pound or more. A small number of fish common to the area is acceptable. If a school of fish enters this zone, tests will be delayed until it leaves.

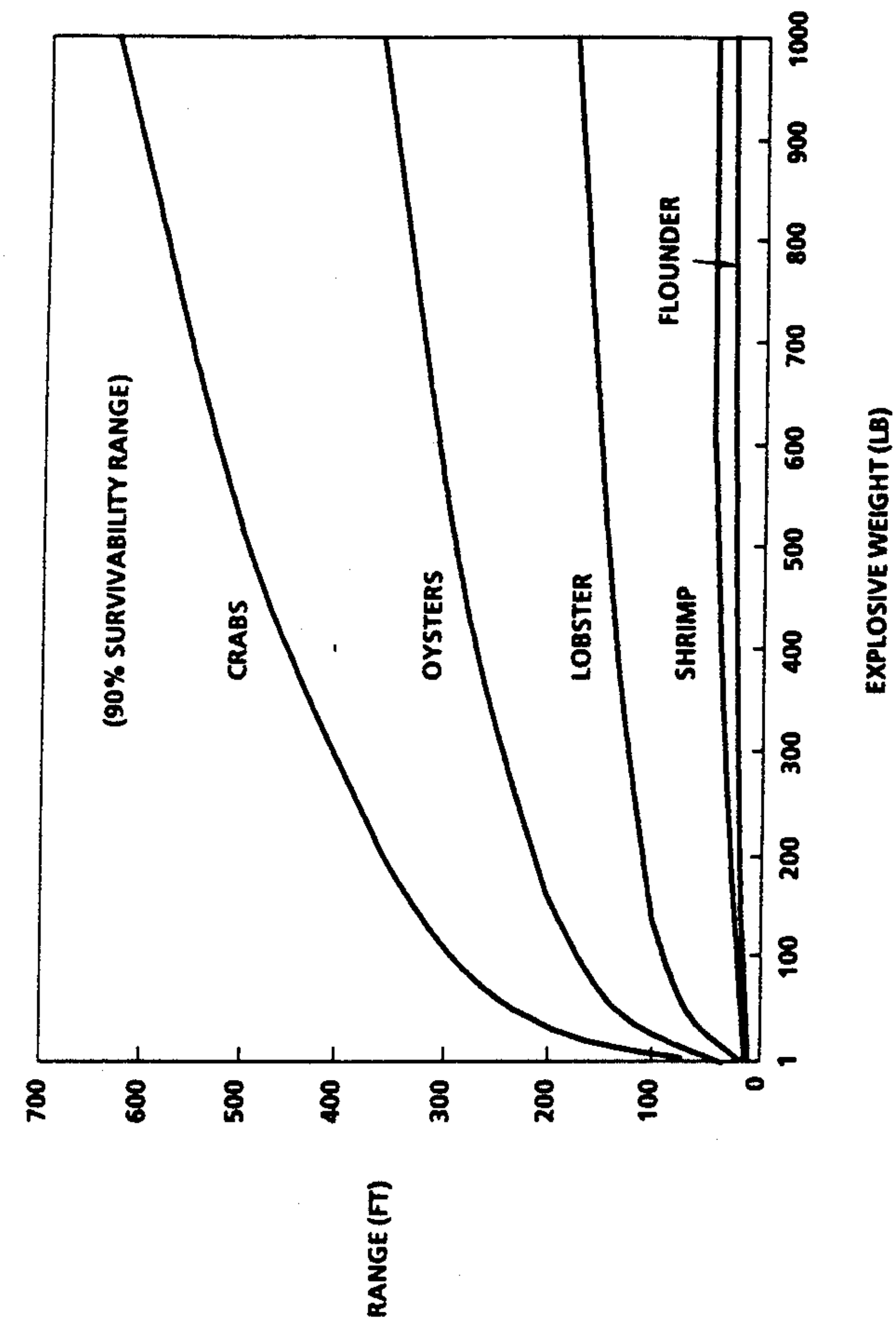

FIGURE 1. CATEGORY I: NON-SWIMBLADDER MARINE LIFE

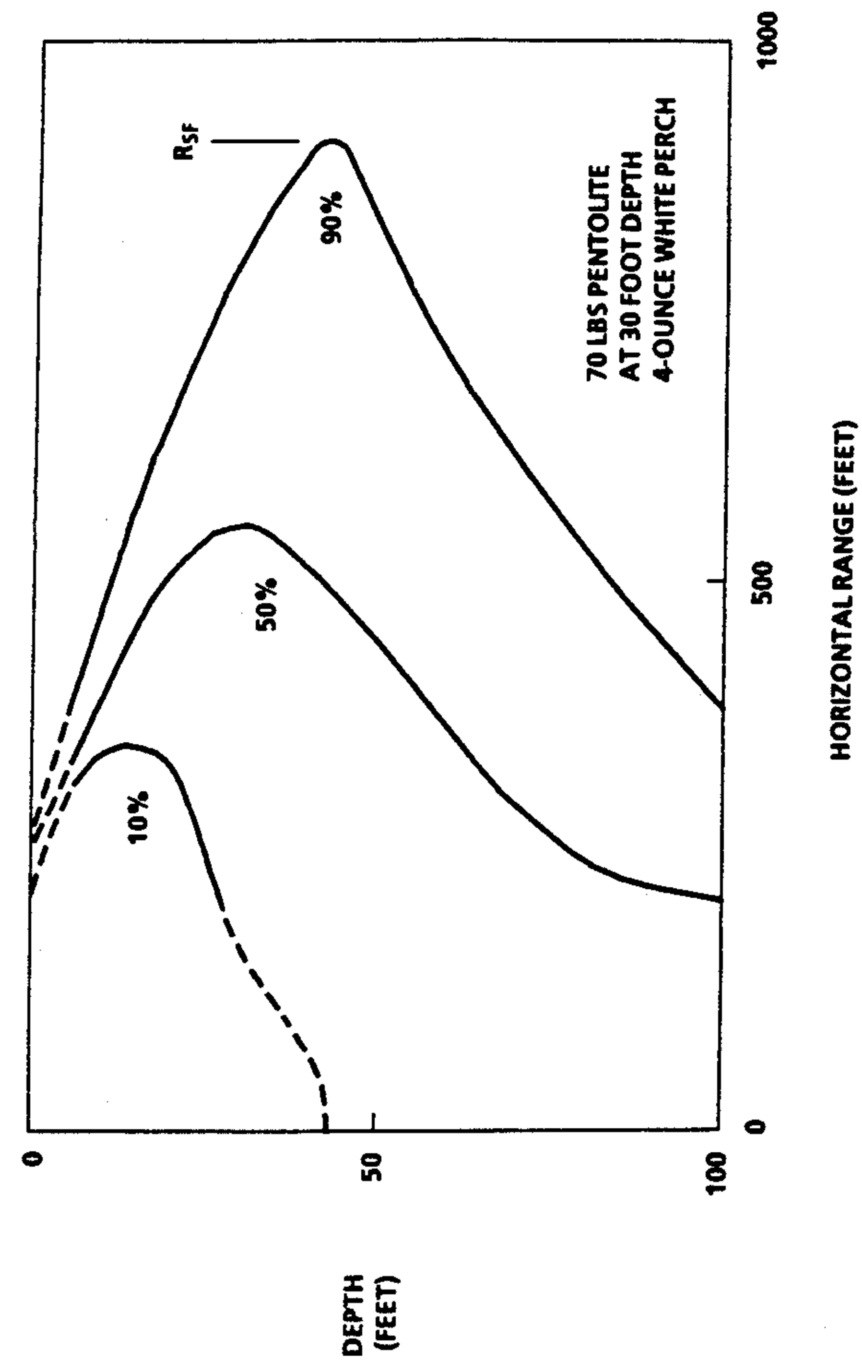

FIGURE 3. CONTOURS FOR SURVIVABILITY OF SWIMBLADDER FISH

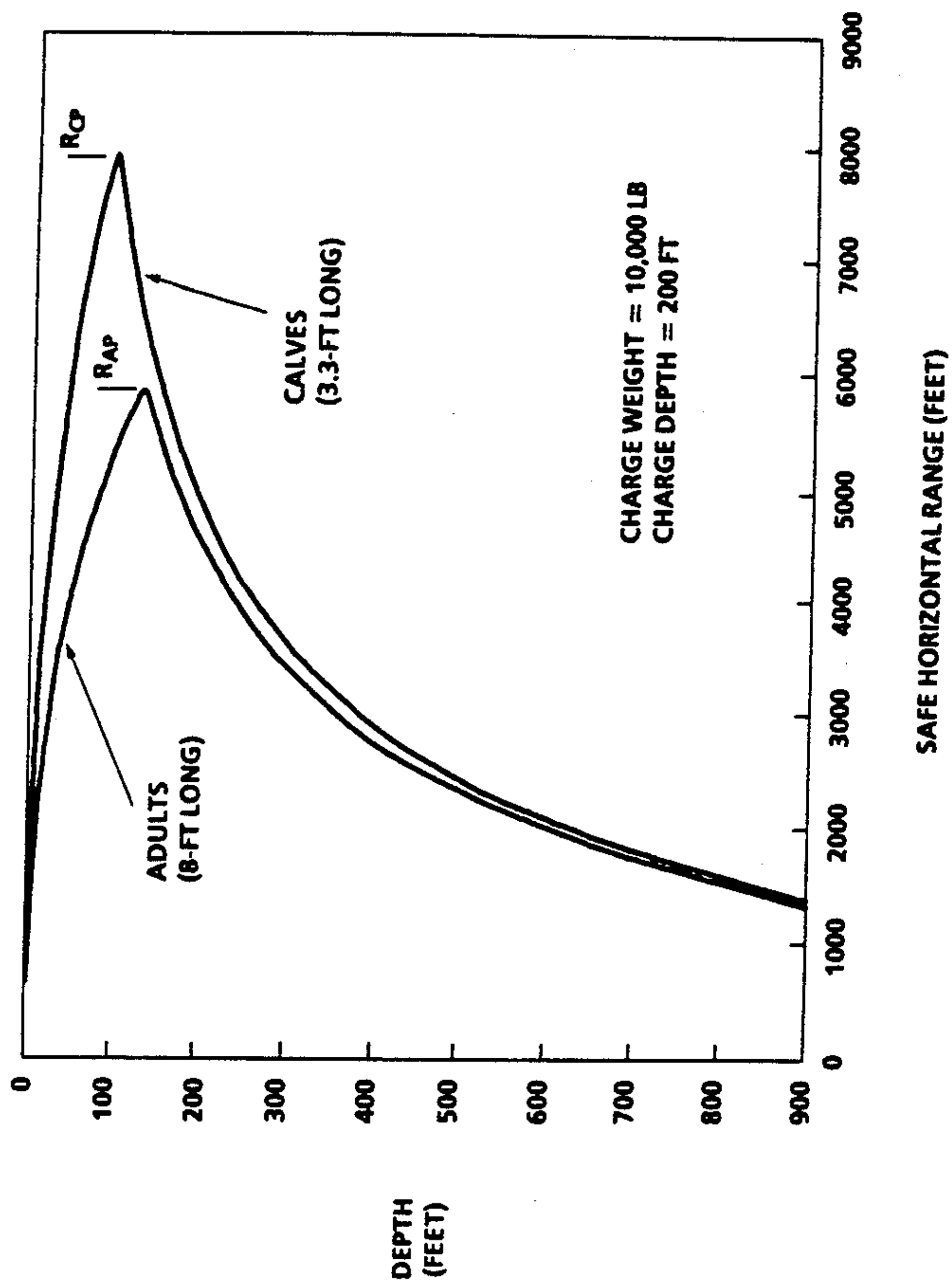

FIGURE 5. CONTOURS FOR SAFE RANGES FOR PORPOISES

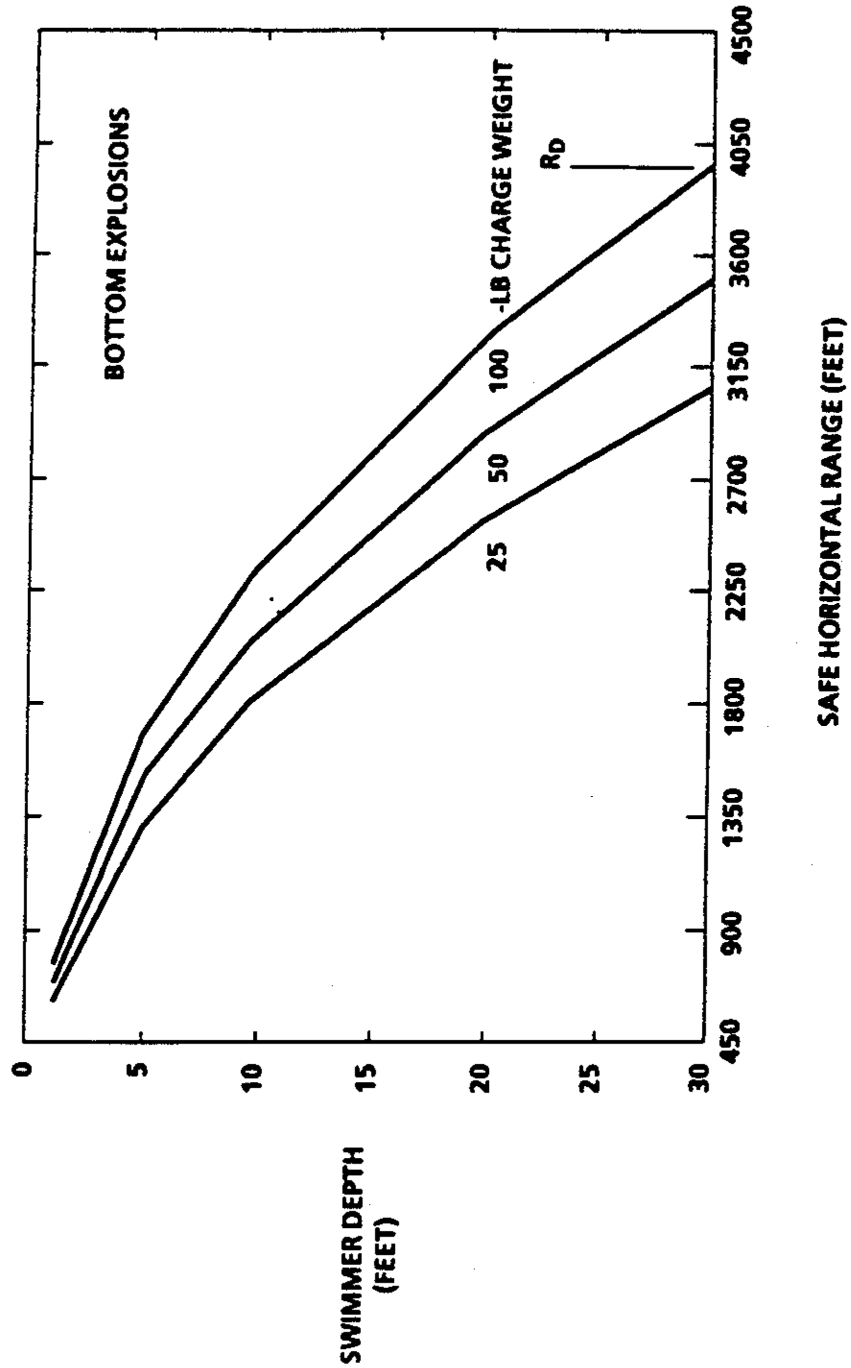

FIGURE 7. CONTOURS FOR SAFE RANGES FOR SWIMMERS IN SHALLOW WATER

TABLE 2. PREDICTION EQUATIONS

CATEGORY I NON-SWIMBLADDER MARINE LIFE–90% SURVIVABILITY

Flounder	$R_{FL} = 3.38\ W_E^{1/3}$
Shrimp	$R_S = 5.39\ W_E^{1/3}$
Lobster	$R_L = 18.5\ W_E^{1/3}$
Oysters	$R_O = 37.4\ W_E^{1/3}$
Crabs	$R_c = 63.4\ W_E^{1/3}$

CATEGORY II FISH WITH SWIMBLADDERS–90% SURVIVABILITY

$$R_{SF} = 95\ W_F^{-0.13}\ W_E^{0.28}(DOB)^{0.22}$$

CATEGORY III SEA MAMMALS AND SEA TURTLES–SAFETY

Calf Porpoise, 200-ft DOB	$R_{CP} = 578\ W_E^{0.28}$
Adult Porpoise, 200-ft DOB	$R_{AP} = 434\ W_E^{0.28}$
20-ft Whale, 200-ft DOB	$R_W = 327\ W_E^{0.28}$
Sea Turtles	$R_T = 560\ W_E^{1/3}$

CATEGORY IV SWIMMERS AND DIVERS–SAFETY

Swimmer and Charge on Bottom, 30-ft DOB	$R_D = 1730\ W_E^{0.18}$
Swimmer Depth 50-ft, 100-ft DOB Deep Water	$R_D = 3800\ W_E^{0.18}$

R = Range in feet

W_E = Weight of Explosive in pounds

W_F = Weight of Fish in pounds

DOB = Depth of Burst in feet

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REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
1 July 1991

3. REPORT TYPE AND DATES COVERED

4. TITLE AND SUBTITLE
Concise Methods for Predicting the Effects of Underwater Explosions on Marine Life

5. FUNDING NUMBERS
PE - 63721N
PR - S0400
TA - S0400

6. AUTHOR(S)
George A. Young

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Surface Warfare Center (Code R10G)
10901 New Hampshire Avenue
Silver Spring, Maryland 20903-5000

8. PERFORMING ORGANIZATION REPORT NUMBER
NAVSWC MP 91-220

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The U.S. Navy has developed methods to predict the environmental effects of underwater explosions and has established procedures to prevent or minimize undesirable effects on marine life. Techniques for predicting the ranges of effects on various marine species and on human swimmers are presented in a concise format for use in preliminary planning.

14. SUBJECT TERMS
Environmental Protection
Marine Life
Explosion Effects

15. NUMBER OF PAGES
22

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAR